Levine, B., Paterson, J. and Burkitt, L., 2017. Phosphorus mitigation project: mitigation of surface P runoff using detainment bunds. In: *Science and policy: nutrient management challenges for the next generation*. (Eds L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 7 pages.

PHOSPHORUS MITIGATION PROJECT: MITIGATION OF SURFACE P RUNOFF USING DETAINMENT BUNDS

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Introduction

Fresh water quality has long been a concern in New Zealand. The indigenous Maori people of Aotearoa/New Zealand recognise freshwater as a taonga (treasure), and have traditional obligations to protect freshwater and "leave a worthy inheritance for future generations" (Land and Water Forum, 2010). The National Policy Statement for Freshwater Management, established in 2011 by the national government, requires regional councils to set objectives that 'maintain or improve the overall quality of freshwater within a region'. In efforts to achieve this goal, regional councils must sustainably manage land use and development, and discharge of contaminants, to safeguard the life-supporting capacity, ecosystem processes and indigenous species of freshwater systems. (Ministry for the Environment, 2011).

Natural waterways receive diffuse pollution from agricultural fields by surface runoff. Small additions of phosphorus (P) to surface water from agricultural runoff have the ability to significantly impact P-limited aquatic systems (Ward et al., 1985). Eutrophication may occur when increased nutrient concentrations drive a bloom of algae or aquatic weeds that interfere with fisheries, recreation, industry, agriculture, human health and drinking water resources. Senescence and decomposition of plants and algae supported by the increased nutrients may result in fish kills due to oxygen shortages in the water (Carpenter et al., 1998). Also, toxic blue-green algae may periodically become the dominant algal type under high nutrient conditions, impacting animal and human health (Ward et al., 1985).

Soils lose P to surface runoff by dissolution, detachment of P from particles, and incidental processes (Ward et al., 1985, Abrahamson and Darkey, 1988). The form of P affects its solubility and susceptibility to mobilization by water (Ward et al., 1985). Whether P goes through solubilisation or detachment mechanisms depends on the physical size of the P compound mobilized (Haygarth et al., 2005). Particulate P attached to soil particles, and soluble P in pore water, are released into surface runoff during erosional events and through interactions between soil and water in the top few cm of topsoil (Jordan-Meille and Dorioz, 2004).

In intensive agriculture, P is lost from the nutrient cycle through product export, animal transfer and via water (Ward et al., 1985). In order to maintain intensive agricultural production, regular inputs of P through fertilisation and supplemental feeding are essential (Abrahamson and Darkey, 1988). However, in some agricultural areas, a lack of consideration for P inputs versus exports has resulted in soil P concentrations that exceed those required for maximum plant growth. This results in a build-up of excess P in soils and increases the risk of P loss to surface runoff (Daniel et al., 1993).

Land use has a significant impact on the diffuse pollution being transported by surface runoff. A study comparing P exported from different land use areas in NZ found pasture catchments exported ~15 times more P than forested catchments on an areal basis (Cooper and Thomsen, 1988). P is added to New Zealand pastoral farm systems to increase plant production to provide food for livestock (Ward et al., 1985). From 1990-2005, NZ had the 2nd highest per cent increase in phosphate fertiliser use, out of 28 OECD countries (OECD, 2007). In 2011, pastoral farms occupied 40% of New Zealand land area (Ministry of Primary Industries, 2017). With such a high proportion of land utilized for pastoral agriculture that requires P inputs, appropriate strategies to prevent nutrients from being lost to natural waterways in New Zealand must be implemented to protect freshwater resources and meet regulatory goals.

Phosphorus issues in Lake Rotorua

Land use intensification, and a growing population in the Lake Rotorua catchment over the past 60 years, has increased nutrient loads entering the lake and caused ecological degradation (Tempero et al., 2015). Identifying appropriate, cost-effective ways to manage nutrient loading into Lake Rotorua is a priority of the Bay of Plenty (BoP) Regional Council and local communities, because poor water quality is impacting the aesthetic, cultural, economic and recreational values provided by the lake. Stakeholders in the Rotorua community would like to restore the lake back to similar water quality levels measured in the 1960s, a Trophic Level Index (TLI), of 4.2. In 2012, a $45.5 million 10 Year Plan was drafted by the Bay of Plenty (BoP) Regional Council, which outlines plans to achieve Lake Rotorua water quality goals (BoPRC, 2012).

Lake Rotorua is both nitrogen- and P- limited, so added P to the system could affect lake water quality. A target to reduce P inputs by 10 tons per year from the lake catchment was set in the 10 Year Plan. Pastoral farming is the primary agricultural practice in the Lake Rotorua catchment and is responsible for ~43.2% of total P entering the lake (BoPRC, 2012). In the Lake Rotorua area, intense rain events (>10mm/hr) of short duration (a few hours), form ephemeral streams on pastoral agricultural land and carry significant amounts of P and sediment to natural waterways (Figure 1). These storms occur ~5-6 times annually (Figure 2) (Clarke, 2013). Therefore, one way to reduce P inputs into Lake Rotorua would be to manage the amount of P being delivered by surface runoff from pastoral agricultural fields triggered by these storm events.

Figure 1. Ephemeral stream (short duration storm water) flowing across a paddock in the Lake Rotorua catchment

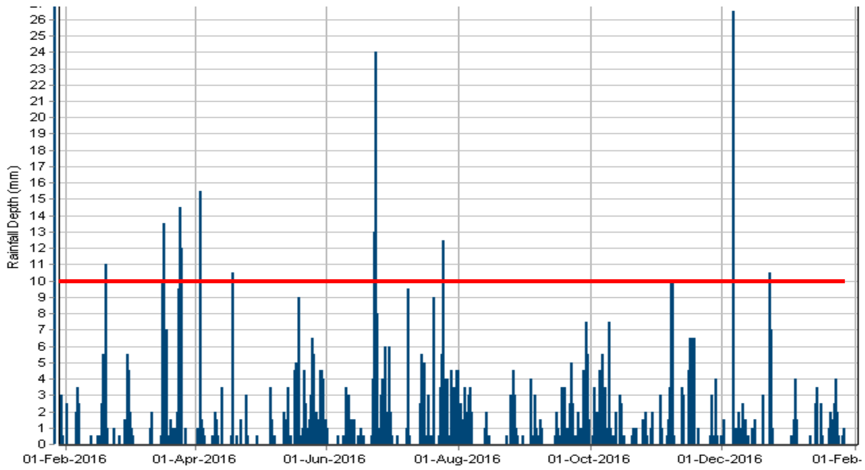

Figure 2. 12 month rainfall graph (2016-2017). The red line at 10 mm/hr marks the usual threshold for when surface runoff commences during rain storms.

Phosphorus Mitigation Project

The Phosphorus Mitigation Project (PMP) is a farmer initiated collaborative effort between national and regional government entities, local farmers, private industries and universities, with the objective to identify cost-effective strategies to reduce the amount of P entering Lake Rotorua by surface runoff. The PMP is interested in ponding surface runoff within farms, to remove P before being discharged to natural waterways.

A thorough investigation of the literature has identified only one published peer-reviewed study that investigated the effectiveness P removal by surface runoff ponding. Results of this study showed that ponds retaining 65 and 76%of sediments from surface runoff lead to P retention efficiencies of 25 and 33%, respectively (Brown et al. 1981). These results suggest that ponding could be an effective strategy at managing P loss from farm catchments

The BoP Regional Council has been developing Detainment Bunds (DB) in the Lake Rotorua catchment since 2010. DBs are storm water retention structures constructed in targeted hydrological pathways within farm catchments and are designed to intercept and pond run-off from ephemeral stream flow (Figure 3). Besides sediment settling by ponding surface runoff, the DB design utilizes an upstand riser which performs a skimming action, decanting the uppermost layer of the ponded water (Figure 4). Participating farmers are tolerant for up to three days of flooding, since longer inundation results in the deterioration of pasture quality. Twenty-two DBs have been constructed on farms in the Rotorua Lakes area since 2010.

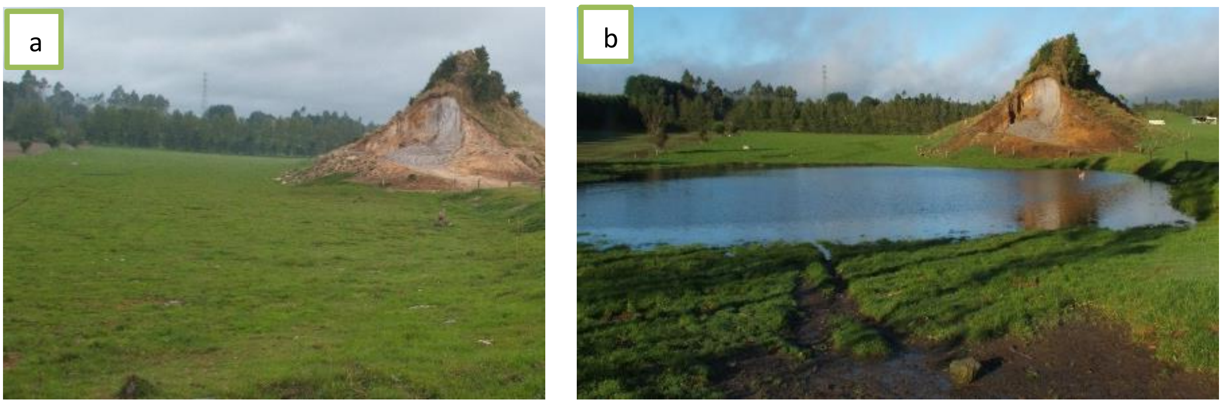

Figure 3. a) DB on dry paddock, b) Water ponded by DB at the same site.

Figure 4. Upstand riser skimming uppermost layer of ponded water

Site selection for DB locations must ensure a low earth wall is able to impound a large amount of water. Previous research by the Rotorua P-Project has identified a ratio of 120:1 (m^3 storage/ha of contributing catchment) as the minimum ponding ratio for site suitability for DB location. Computational scoping with LiDAR 1m contour data and GIS programs, allow efficient identification of potential DB sites and 'mock up' drawings to 'try fit' the DB design on the landscape.

DBs are designed to have 3 water outlets (Figure 5) including:

- A small, restricted drain hole at the base of the upstand riser, which can be plugged for the ponding duration (Figure 5a)
- A large culvert pipe that passes through the DB which is connected to the upstand riser (Figure 5b)
- An overland spillway as a contingency for massive rain events (Figure 5c)

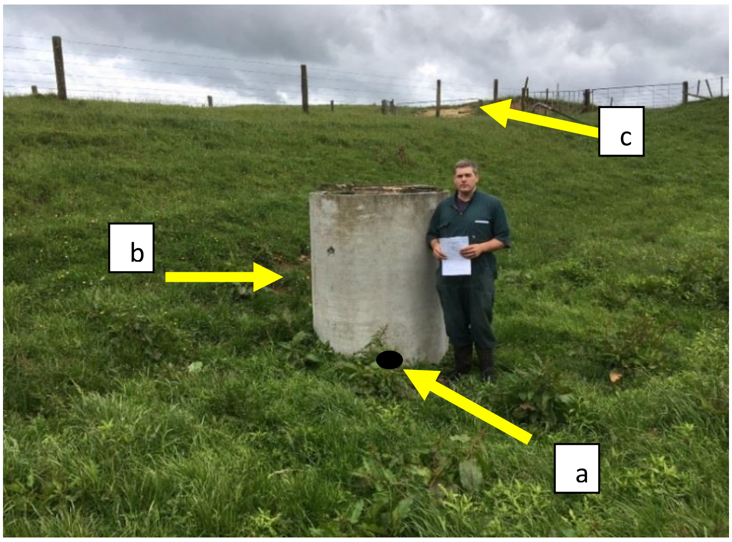

Figure 5. Concrete pipe riser showing restricted drain hole at base (a), skimming riser with large cultert (b) and emergency spillway (c).

An earlier Master's thesis investigated the performance of DBs to attenuate P and sediment loss from pastoral farm catchments in the Lake Rotorua area (Clarke, 2013). The study analysed settled sediments and grab samples of storm water passing through the DBs at 3 of the 22 DB sites. Results showed that ponding water for 3 days behind a DB allows P associated with soil sediment to settle out of the water column (Figure 6) and sediment retained within DBs on the farm had a higher P concentration than sediment found in bed deposits in downstream receiving water bodies (Figure 7). These results show a 'proof of concept' for the efficacy of the DB design (Clarke, 2013).

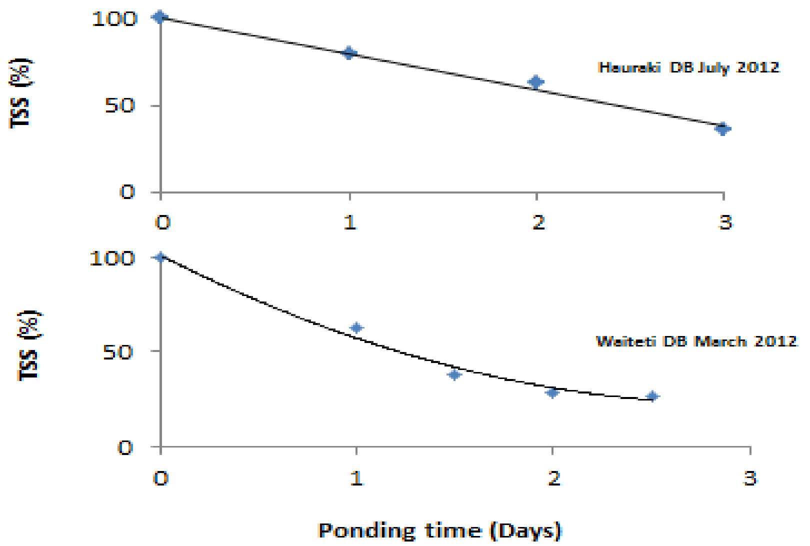

Figure 6. Total suspended solid loads in ponded water column decreasing over 3-day period. Source: Clarke, 2013.

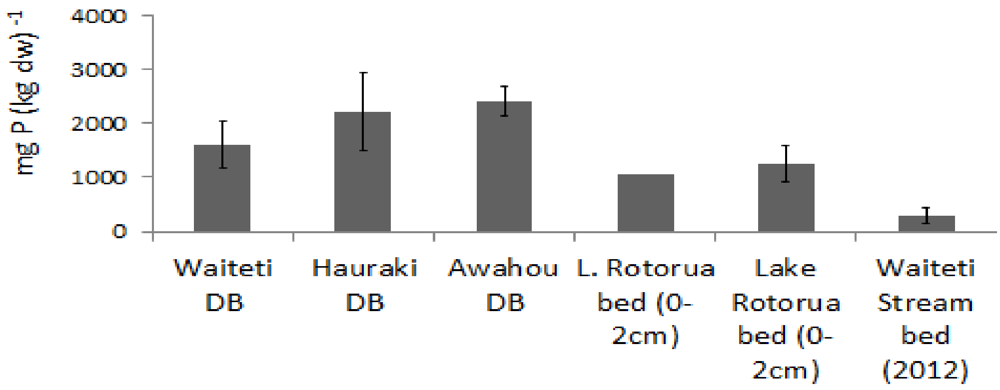

Figure 7. Comparison of P concentration in sediments detained by DBs and those in beds of receiving waters. Source: Clarke, 2013.

The current 'Phosphorus Mitigation Project' Ph.D. research will test the effectiveness of DBs as a way to manage P runoff from pastoral farmland and investigate the mechanisms involved with P attenuation by ponding. Data and sample collection over a 3-year period will attempt to identify specific quantities and fractionation of P entering and leaving the DB. Mechanisms and processes affecting P dynamics under ponded conditions will be investigated to advance understandings, and potentially optimize the DB operating strategy.

The objectives of the Ph.D. research are to:

- Determine the effectiveness of DB's to reduce P loss generated from surface runoff.
- Quantify performance of DBs to enable credit to participating farmers for P-capture capability
- Assist decision makers in determining if DBs can be promoted as a practical P-loss mitigation tool suitable for NZ farms
- Propose DBs as a P-loss mitigation tool (dependent on research findings) in nutrient budgeting models.

To achieve these objectives the following methods and measures will be implemented:

- Inflow and outflow volume and P load from DB's will be measured.
- Examine the forms of P (soluble vs. particulate) delivered into and being released from DB ponds
- Measure P fractionation and load within the DBs ponded water column

Acknowledgements
The Phosphorus Mitigation Project is funded by DairyNZ, Beef + Lamb NZ, NZ Deer Industry, the Sustainable Farming Fund, Ballance Agri-Nutrients and three Regional Councils. Supporting institutions include Massey and Waikato Universities with advisory assistance from staff at NIWA and Lincoln University.

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